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(11) Publication number : **0 474 449 A2**

(12)

## EUROPEAN PATENT APPLICATION

(21) Application number : **91308019.8**

(51) Int. Cl.<sup>5</sup> : **F16L 11/118, F16L 11/11,  
B29C 53/30, B29D 23/18**

(22) Date of filing : **02.09.91**

(30) Priority : **01.09.90 GB 9019088**

(43) Date of publication of application :  
**11.03.92 Bulletin 92/11**

(84) Designated Contracting States :  
**AT BE CH DE DK ES FR GB GR IT LI LU NL SE**

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(54) **Improvements in plastic tubing.**

(57) A corrugated plastics tubing (10) which may be corrugated on its inner surface as well as its outer surface, has corrugations (12) which define a series of peaks (14) and roots (16) along the tube. The thickness ( $W_1$ ) of the walls (18) of the roots (16) are reduced in thickness from a standard thickness ( $W_0$ ) or the peak wall thickness  $W$ .

The tube is made by compressing the tube at the root wall region (16) so as to displace material from that region. By applying a compression force sufficient to take the plastics of the tube beyond its elastic point, beneficial properties can be attained.

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The present invention relates to plastics tubing and a method of manufacturing same. More particularly it relates to corrugated plastics tubing and a method of manufacturing same.

In order to produce plastics tubing which is flexible, preformed annular plastics tubing has to date been selectively shaved to introduce circumferential corrugations, or plastics tubing has been preformed by processes which concertina the plastics material as it sets. Thus, the method of the present invention differs in that it displaces material by compression.

The corrugated products made by those processes which concertina the product have walls which are substantially uniform in thickness throughout. The methods used have of course on occasions resulted in products which are not as uniform in thickness as has been desired. Tape wrapping or mandrel-less vacuum forming, methods which bend or introduce folds into the tube, have a tendency to produce a corrugated tube with very slightly thinner radially outwardly projecting peaks and very slightly thicker radially inwardly projecting roots. However, these products are screened so that only those of substantially uniform thickness are selected. This is because it has been suggested that if the inner wall is thicker or thinner than the outer wall, the product will suffer from less than optimum flex-life, burst strength, and abrasion resistance. Processes using a wire and mandrel and a plain cylindrical tube also produce uniform products.

These preforming processes concertina or fold the tube by exerting a force at points along the tube sufficient to cause localised bending of the plastics, but insufficient to cause displacement by compression of the tube. In other words, the force acts in a retaining sense, simply to hold a corrugated form during heat treatment. In this way the desired shape is maintained until the plastics has set.

It has unexpectedly been found that, by making the root walls of a corrugated tube thinner than the peak walls favourable characteristics in the tube are produced without detrimental effect to the product.

The preferred way of achieving this has been to displace material from the root region of the tube using compressive forces.

It has been found that, for example:

- (1) The flexibility of a product having a given inside diameter and outside diameter or a given mass per unit length can be increased by reducing the thickness at the roots,
- (2) The minimum bend radius can be decreased for a product having a given inside diameter and a given outside diameter by reducing the wall thickness at the roots, and
- (3) Increased flexibility and a decreased minimum bend radius of smooth bore tubing can be obtained by reducing the wall thickness at the roots.

The displacement resulting from compression

can also be responsible for providing an increase in crush resistance for a product with a given mass per unit length.

Furthermore, where the products are made from PTFE and have not been cut away, the structure can be returned to its original form by heat treatment.

In accordance with one aspect of the present invention there is provided a corrugated plastic tube in which the corrugations form peaks and roots and in which the wall thickness at the peaks, is greater than the wall thickness at the roots.

Accordingly there is provided a corrugated plastics tube, having a wall with an inner surface and an outer surface, and corrugations which define a series of peaks and roots along the tube, characterised in that the thickness of the wall between the inner surface and outer surface of the wall at the peaks, the peak wall thickness  $W$ , is greater than the thickness between the inner surface and outer surface of the wall at the roots, the root wall thickness  $W_1$ .

In accordance with a further aspect of the present invention there is provided a method of producing such a product, which method is characterised in that a tube is thinned in its root region by the application of a compressive force, which compressive force displaces material from the root region of the tube.

That compression has been used to displace, as oppose to remove material, can be checked in the case of PTFE by seeing if the product can revert to its original form under heat treatment.

For other thermoplastics such a high density polyethylene, the product of the invention can be distinguished from the prior art by testing its tensile strength at break point. The product of the invention will have a much greater tensile strength at break point than a product with an equivalent cross sectional area which has not been subjected to compression to displace material in the root region.

The reason for this can best be explained by considering the relationship between stress and strain on a thermoplastics tube. The application of stress (i.e. a compression which gives rise to displacement) puts a strain on the material and gives rise to an extension.

Fig. 8 is representative of a typical stress/strain relationship for high density polyethylene at different temperatures. As the stress is increased, the HDPE is displaced and gets thinner. Under a given stress it reaches its elastic point "E". Up until this point the stretch is reversible. Once the elastic point is reached the product is irreversibly stretched, and will go on to break when its breaking point "X" is reached. If it is released after it has been stretched beyond its elastic point, it can only contract by a little (some 8 % at 23°C). Referring to Fig. 8, it can be seen that at 23°C the breaking point X is reached at a stress of 45N/mm<sup>2</sup> or under a strain of 450%.

At the breaking point 'X', the area of the sample can be shown by experiment to have decreased by

5.5 fold. Thus the apparent stress of 45 N/mm<sup>2</sup> is really a stress of 45x5.5 or 247.5 N/mm<sup>2</sup>.

Thus by thinning the root for a given volume of material, greater flexibility can be achieved. To do this the material of the tube should be compressed to displace the material. The force applied should be sufficient to take the material beyond its elastic point but just short of its breaking point X to give maximum flexibility.

The material may also be compressed to beyond its breaking point X to give even greater flexibility, but a reduction in tensile strength will also result.

The volume of the material should remain substantially unchanged, since it is the resulting displacement of material, at substantially 90° to the compression force, which gives rise to the beneficial results.

It has been found that HDPE may be compressed and displaced to 20% of its original wall thickness (= 400% tensile strain) at 23°C before a reduction of tensile strength begins to occur.

Similarly HDPE may be compressed and displaced to 14% of its original wall thickness (=600% tensile strength at 60°C )before reduction of tensile strength begins to occur.

A simple way to check the difference between a product in which the root region has been thinned by displacement and a moulded or machined equivalent is to perform a tensile test on the finished product. Providing equivalent materials are used, the compressed and displaced product will fail at a substantially higher tensile load:- For example, a tube compressed to 14% of its original wall thickness at 60°C can be subjected to 7 times the tensile load of an equivalent uncompressed product without failure.

It will be apparent that, various materials and processing temperatures may be used to produce a product according to this patent.

The aforementioned product can be produced by taking a state of the art convoluted plastics tube, such as that manufactured according to UK Patent No. 1543586. The convoluted plastics tube is slid over a suitably sized close fitting mandrel. A helical tool with an internal diameter which is greater than the outside diameter of the mandrel, but less than the combined diameter of the outside diameter of the mandrel and twice the wall thickness of the convoluted plastics tube is brought into contact with the tube so that a pressure sufficient to displace material from the root region thereby thinning it is achieved. Heating is preferable but not essential. The leading end of the tool is kept hot whilst the following end of the tool is kept cold. The helical tool is then helically wound along the mandrel allowing sufficient time to permit the hot end of the tool to warm up the plastics material to heat treatment temperature at the root region of the tube. The helical tool (and rolling elements may be included with the helical tool depending on the configuration

required and the plastics used) is continually wound to the end of the tube where the finished plastics tube with roots which are thinned, i.e. in which the peak wall thickness is greater than the root wall thickness, is produced.

Furthermore, different shapes can be produced. In one embodiment a single start spiral corrugation may be formed. Alternatively multiple start spiral corrugations, annular corrugations, axial corrugations or a combination thereof can be produced. The specific shapes can be altered, and further examples are given with reference to the specific description.

By reducing the wall thickness at the roots of the corrugations to approach 1% of the original or peak wall thickness the most favoured results can be obtained. Thus a reduction by between 3% through 95% to 99%, more preferably 10% through 95% to 99% of the peak wall thickness is preferred since the flexibility of the tube is improved, and thus a lower force is required to bend a given length through a given angle.

The preferred percentage will be dependent on the thermoplastic used.

For high density polyethylene, it is preferred to thin the original wall to as little as 5% of its original value i.e. the wall thickness should be reduced by 95%.

To benefit substantially from the thinning, the root wall should be thinned from 60% to 1% of its original value, though 50%, 40%, 30%, 20%, 10% and 5%.

For PTFE the root wall should be thinned from 60% to 5% preferably 50% to 5%, of its original value. For a fully corrugated shape the root wall should be thinned from 60 to 20% preferably 50% and for a smooth bore shape from 20% to 3% preferably 10%.

Other thermoplastics such as polyethylene and polypropylene can be thinned to similar degrees.

Furthermore, a reasonable width to the thinned region is preferred.

Likewise a radiussed rather than square edge to the thinned region is preferred.

As far as the width of the thinned area is concerned, working from original wall thickness, the width should be 10% - 200% of the peak wall thickness for smooth bore type constructions and typically 30 - 600% of peak wall thickness for fully corrugated constructions. As the width tends to a greater percentage so the flexibility of the product increases.

If the corrugations are made using compressive forces to displace material, as opposed to by removing material, an increase in crush resistance may be achieved.

Specific embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Fig.1 is a perspective view, in part longitudinal-section, of a circumferentially corrugated tube according to one aspect of the invention;

Fig.2 is an enlarged longitudinal-sectional view, in exaggerated form, of part of the tube of Fig.1; Fig.3 is an end view of a second embodiment of the invention, which shows axial corrugations; Fig.4 is an end view of a third embodiment showing axial corrugations;

Figs. 5a, 5b, 5c, 5d and 5e are longitudinal sectional views of one side only of further embodiments of radially corrugated tubes;

Fig.6 is a diagrammatic representation comprising two tubes; (a) a standard corrugated tube and (b) a tube which has been compressed so that displacement occurs. It shows the comparative areas at their respective roots and peaks when each has been made from a given weight of plastic;

Fig.7 is a diagrammatic representation showing the resulting stiffness and minimum bend radius that result when the wall thicknesses at the root of a tube is altered relative to that of a standard; and

Fig. 8 is a graph of stress vs strain for HPDE thermoplastics.

Fig.1 shows a plastic spirally corrugated tube 10 having an outermost or outside diameter OD and an innermost or inside diameter ID. The tube corrugations 12 define a series of peaks 14 and roots 16. The tube has a minimum bend radius MBR which is determined by experiment and is the radius around which the tube may be bent so that the inside diameter is reduced to not less than 85% of its normal (unbent) inside diameter. The tube is a single start helical corrugated tube. Its corrugations enable the tube to be bent around an object without substantially reducing the inside diameter, that is the tubing may be bent around corners or flexed without impeding flow of liquids or fluids through the tube. By decreasing the minimum bend radius the tube can be bent more tightly. The flexibility of the tube can be increased by introducing more corrugations for a given length and decreasing the root wall thickness. The number of corrugations is expressed as turns per inch (TPI) and the tube 10 has a TPI of 3 (3 turns per 25.4 mm).

The invention can be more clearly explained by referring to Fig.2.

The PTFE tube 10 has a root wall thickness  $W_1$  which is less than the peaks wall thickness  $W$ . Where the root wall thickness  $W_1$  has been reduced during construction from a standard wall thickness  $W_0$  by compressing the tube to displace material the corrugated tube can be caused to revert to a non-corrugated form, of thickness  $W_0$ , its original thickness by heat treatment.

This phenomena is peculiar to PTFE.

If during the tubes construction, the root wall thickness  $W_1$  has been reduced by cutting plastics away, then the product can not revert to its original form.

Furthermore compression and displacement can cause the peak wall thickness to be greater than the original wall thickness  $W_0$ , and again if the tube is constructed of PTFE it is capable of reverting to its original form of wall thickness  $W_0$  on heat treatment.

The effect of reducing  $W_1$  relative to  $W$  can be seen more clearly with reference to Fig.7 which shows the effect of altering the root wall thickness  $W_1$  and/or the peak wall thickness  $W$  relative to  $W_0$ , a standard wall thickness.

Fig.7 shows the resulting stiffness and MBR for PTFE tubing by comparison to a tube having a TPI value of 9, (9 turns per 25.4mm) a standard wall thickness  $W_0$  of 0.027 inches (0.68mm), an inside diameter of 0.350 inches (8.89mm) and an outside diameter of 0.500 inches (12.7 mm).

Different PTFE tubes were made in which only the wall thickness was altered. The root wall thickness  $W_1$  was decreased, or the peak wall thickness  $W$  was increased.

To determine the flexibility (stiffness), six inch long (152.4mm) corrugated tubes were bent through 90 degrees and the force required measured. From the results obtained it was apparent that the relationship between the rootwall thickness  $W_1$  and the stiffness was as follows:

Stiffness  $\propto K (W_1)^2$ , and by similar experiment  $MBR = K (W_1)$  where  $k$  is a constant i.e. doubling  $W_1$  relative to  $W$  or  $W_0$  quadruples stiffness;

(decreasing  $W_1$  relative to  $W$  or  $W_0$  increases flexibility) and doubling  $W_1$  relative to  $W$  or  $W_0$  doubles the minimum bend radius.

By making  $W_1$  approximately  $0.95 \times W$  or  $W_0$  it has been found that an improvement in flexibility of about 10% results. It has been found that to increase flexibility to a maximum  $W_1$  should be at least  $0.03 \times W$  and preferably  $0.01 \times W$ . This has been found to be the practical limit beyond which irreversible damage occurs.

By making  $W_1$  smaller the crush resistance of the tube may also improve. Referring to Fig.6, comparison of Figs. (a) and (b) indicates that the tube embodying one aspect of the invention, whilst having a total area identical to the standard tube (and which also has an equivalent weight per unit length), has a reduced area at the root of the corrugation, by comparison with the walls of a standard tube thus giving a relative increase in the outer diameter of the tube in comparison with a standard tube. This relative increase in the outside diameter provides a greater crush resistance for a structure containing the same weight of plastics because the second moment of area of the wall section is increased.

Other examples of radial corrugations are shown in Fig.5. Fig.5a shows a radially corrugated tube in part cross section. The tube has roots 16 each having walls 18 of reduced wall thickness  $W_1$  and peaks 14 having walls 20 of standard thickness  $W_0$ . The inner

face 22 against which fluid passes when passing through the tube is therefore also corrugated. It does, however, have planar portions 24 and inwardly concave portions 26.

The configuration shown in Fig.5b has greater flexibility than that shown in Fig.5a, but has poorer flow qualities due to the inner face 22 being alternately inwardly convex 28 and inwardly concave 30.

The configuration shown in Fig.5c provides better flow qualities since the central bore is planar and not corrugated, yet due to the provisions of corrugations on the outermost wall, has added flexibility.

The configuration shown in Fig.5d produces the greatest flexibility due to the tightness of the corrugations. For similar reasons the configuration in Fig.5e produces great flexibility.

In order to provide radial flexibility, axial corrugations can be introduced, as shown in Fig. 3. In such forms the peaks 14 and roots 16 extend along the tube's main axis. The reduced root wall thickness  $W_1$  compared with the peak wall thickness  $W$  gives rise to improved compressibility i.e. decreased crush resistance.

As a result of compressing the root 16 to give a reduced wall thickness  $W_1$ , displacement can also occur giving rise to a wall thickness  $W$  which is increased compared with the standard wall thickness  $W_0$ .

## Claims

1. A corrugated plastics tube, having a wall with an inner surface and an outer surface, and corrugations which define a series of peaks and roots along the tube, characterised in that the thickness of the wall between the inner surface and outer surface of the wall at the peaks, the peak wall thickness  $W_1$  is greater than the thickness between the inner surface and outer surface of the wall at the roots, the root wall thickness  $W_1$ .
2. A tube as claimed in claim 1 in which the inner surface of the tube is substantially planar.
3. A tube as claimed in claim 1, in which the inner surface of the tube is corrugated.
4. A tube as claimed in any of the preceding claims in which the root wall thickness is between 97% and 1% of the original or peak wall thickness.
5. A tube as claimed in any of the preceding claims which tube has been subjected to a compression force to displace material in the root region.
6. A tube as claimed in claim 5 wherein a compression force applied was sufficient to take the plas-

tics of the tube beyond its elastic point.

7. A tube as claimed in any of the preceding claims in which the corrugations extend radially about the tube.
8. A tube as claimed in any of the preceding claims in which the corrugations extend axially about the tube.
9. A tube as claimed in any of the preceding claims in which the plastics is a thermoplastics.
10. A tube as claimed in claim 2, in which the root has a width of between 10 and 200% of the peak wall thickness.
11. A tube as claimed in claim 3, in which the root has a width of between 30 and 600% of the peak wall thickness.
12. A tube as claimed in any of the preceding claims, in which the root is radiused.
13. A method of producing a corrugated tube having a series of peaks and roots characterised in that the tube is thinned at its root region by the application of a compressive force which compressive force displaces material from the root region of the tube.
14. A method as claimed in claim 13, in which the compressive force is sufficient to take the plastics of the tube beyond its elastic point.

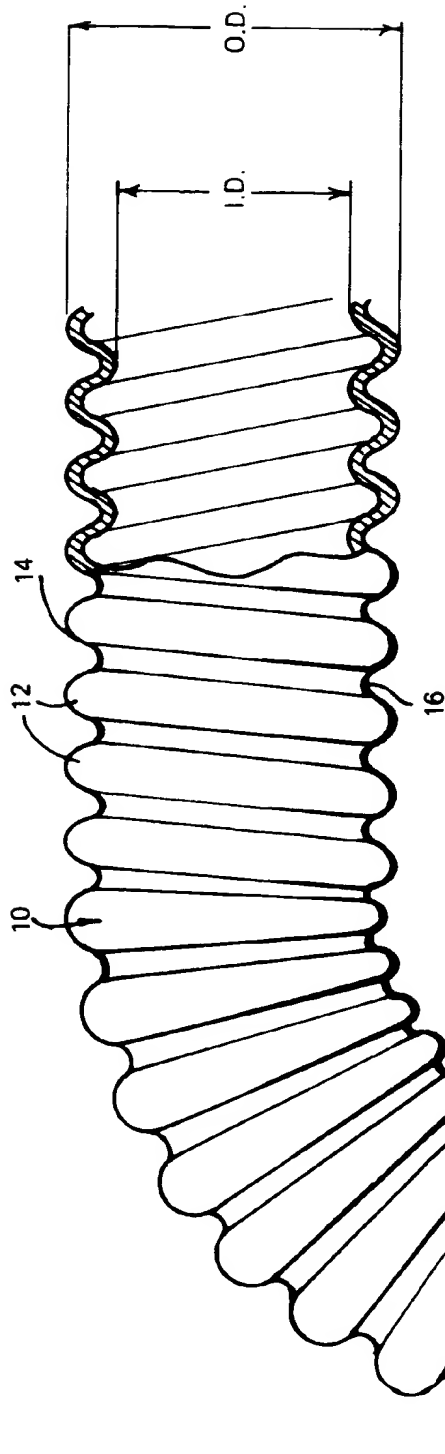


FIG. 1

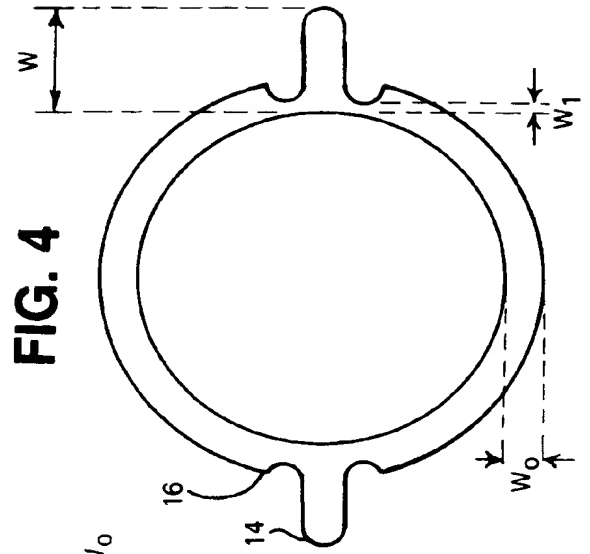


FIG. 4

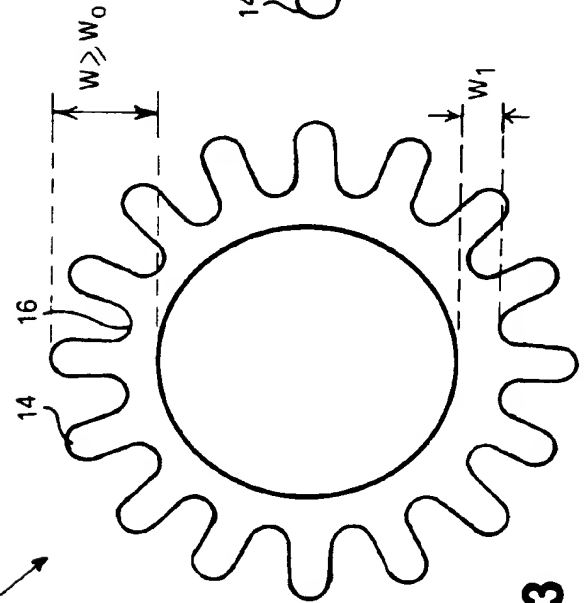


FIG. 3

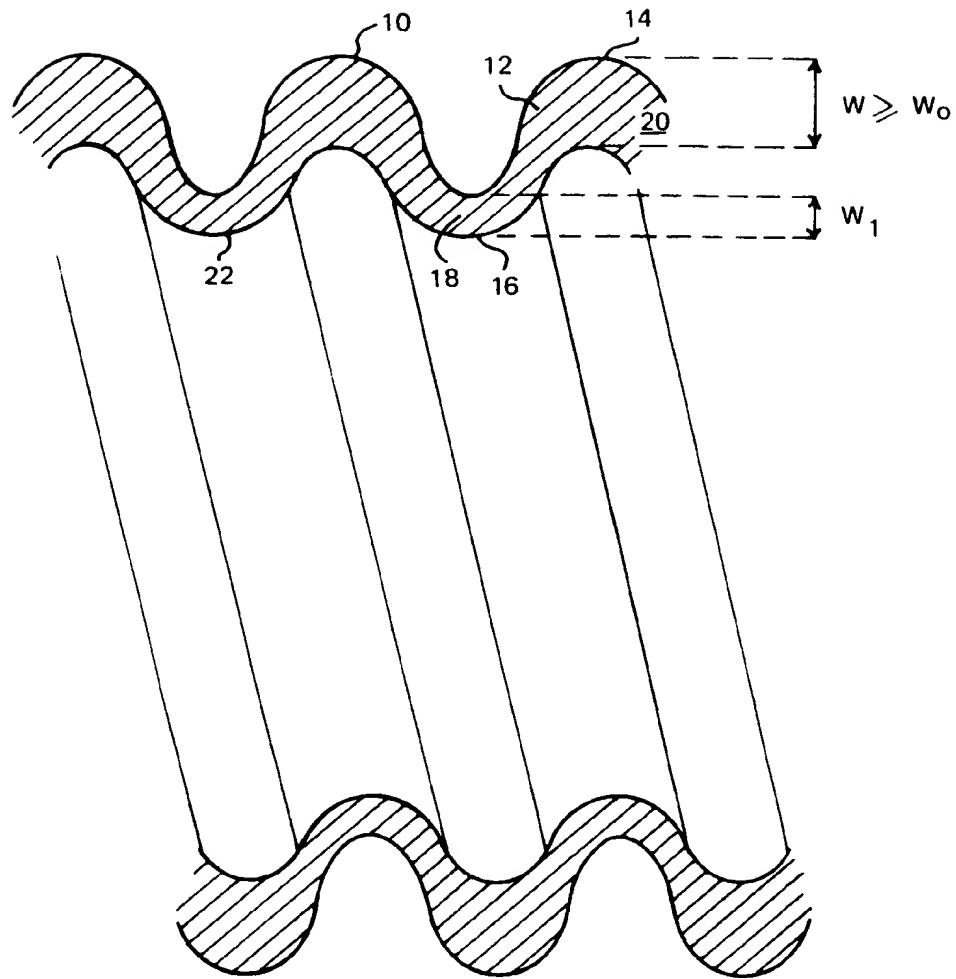


FIG. 2

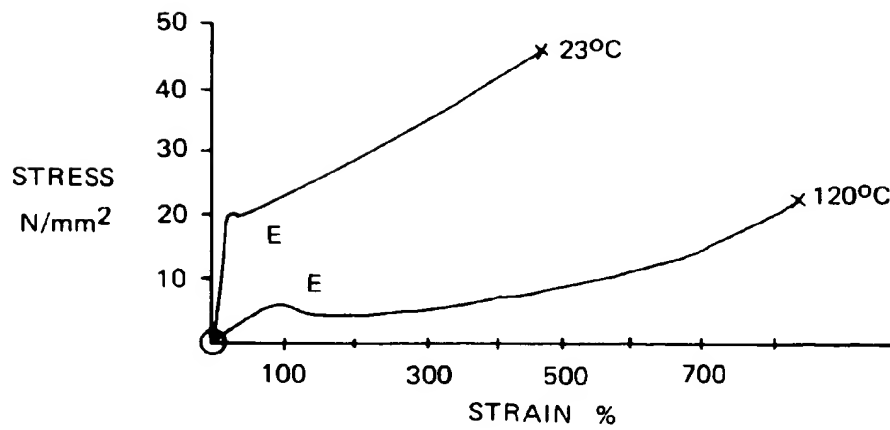


FIG. 8

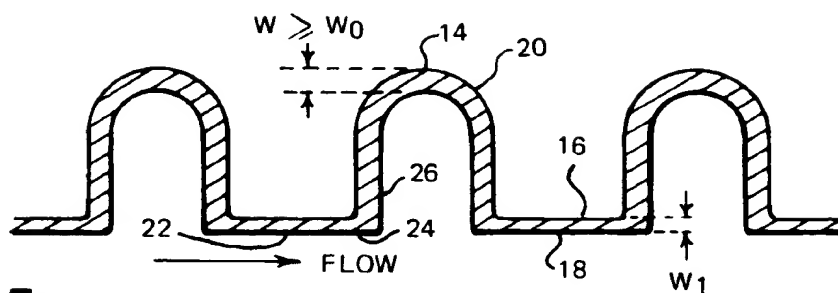


FIG. 5a

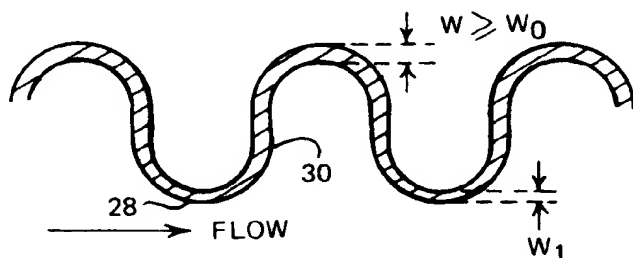


FIG. 5b

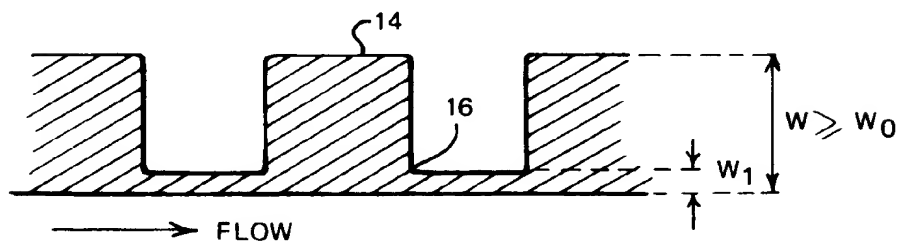


FIG. 5c

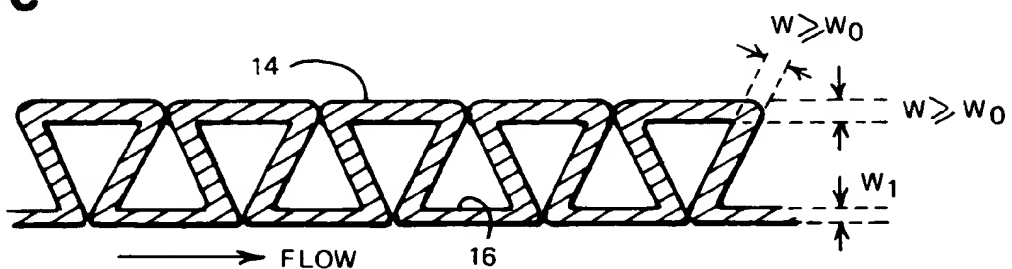


FIG. 5d

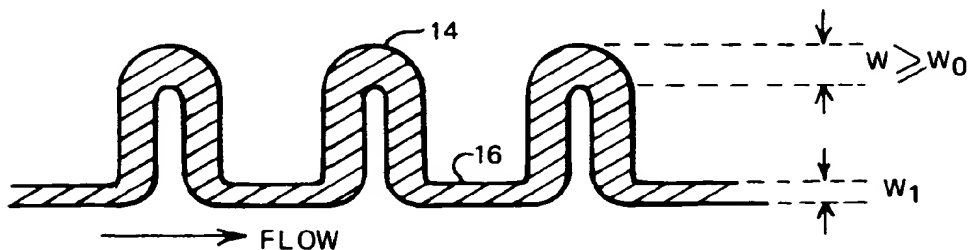
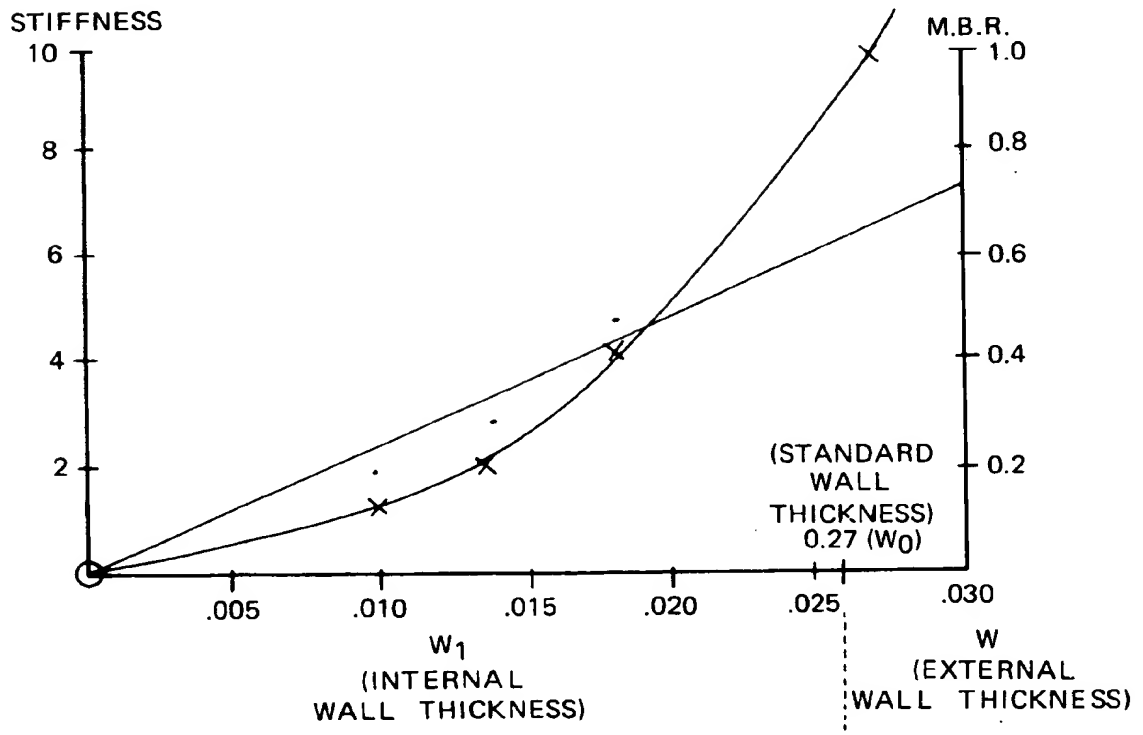
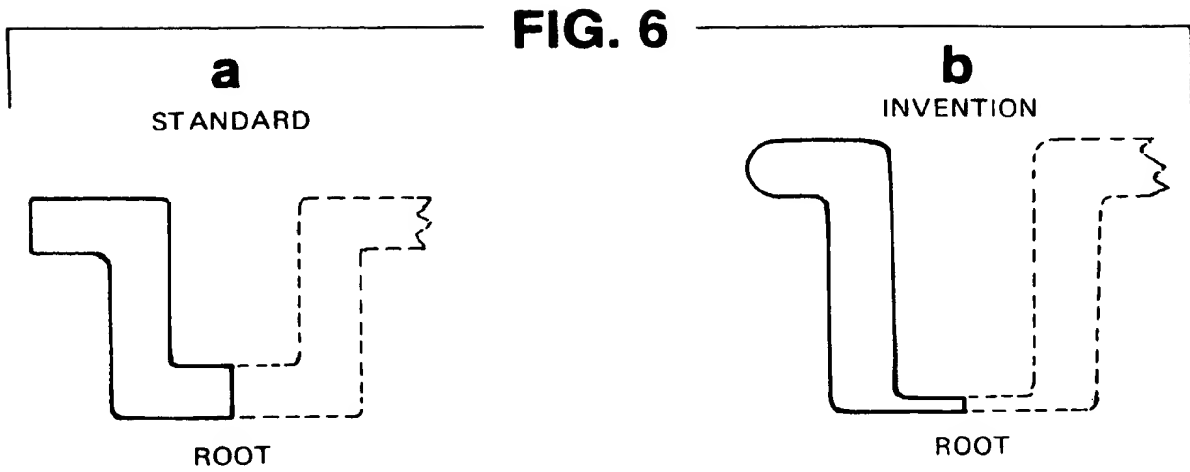


FIG. 5e





**FIG. 7**

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